

521,744

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
9 June 2005 (09.06.2005)

PCT

(10) International Publication Number
WO 2005/053094 A1

(51) International Patent Classification⁷: **H01Q 3/26, H04B 17/00**
(21) International Application Number: **PCT/GB2004/004896**
(22) International Filing Date: **19 November 2004 (19.11.2004)**
(25) Filing Language: **English**
(26) Publication Language: **English**
(30) Priority Data: **0327041.0 21 November 2003 (21.11.2003) GB**

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

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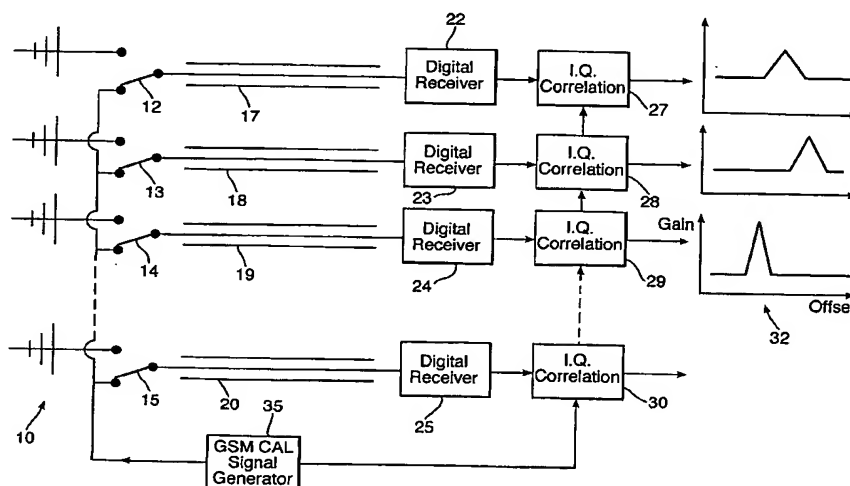
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(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: **WIDEBAND ANTENNA AND RECEIVER CALIBRATION**



(57) Abstract: A method is provided for calibrating an antenna and receiver system having multiple channels, each channel having an antenna, cable feed and associated receiver components, the method comprising the steps of: (i) applying a wideband calibration signal to each antenna feed, the wideband calibration signal having similar characteristics to an operational signal; (ii) measuring a correlation response across a plurality of said channels; (iii) deriving an estimate of signal transfer response for each of said plurality of channels based on the correlation response; and (iv) applying compensation factors for each of said plurality of channels derived from the estimate of signal transfer response.

WO 2005/053094 A1



Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

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WIDEBAND ANTENNA AND RECEIVER CALIBRATION

The present invention relates to antenna calibration and more particularly, but not exclusively, to a method of calibrating a wideband antenna and receiver system. The method of calibration is particularly, though not
5 exclusively, suitable for use with phased array antennae, particularly of the type found in mobile cellular telephone systems used for the reception of wideband signals and employing digital receivers and digital signal processing techniques.

Mobile cellular telephone systems usually comprise a network of base
10 stations operable to communicate with mobile handsets of users (subscribers) in order to provide telephone and other services.

The operational range of base stations in mobile telephone systems is typically of the order of 10 – 20 kilometres (km).

Typically, the power of signals transmitted by base stations is of the
15 order of a few tens or even hundreds of Watts. The frequency of the signals is usually in the low microwave region of the electromagnetic spectrum, typically around the 1 – 2 GHz range. This range of frequencies is found in Global System for Mobile (GSM) cellular mobile telephone networks in particular. Mobile communications systems operating according to other mobile
20 communications standards, whether cellular or otherwise, have corresponding operational frequency ranges. Examples of other mobile communication systems include digital audio broadcasting (DAB) systems, coded division multiple access (CDMA), Quadrature Phase Shift Keying (QPSK) communication systems, High Performance Radio Local Area Networks
25 (HIPERLAN) and Universal Mobile Telecommunication Systems (UMTS) telephone networks.

Signals generated in such systems occupy a wide bandwidth and are often modulated with pseudo-random codes or sequences that have a good auto correlation function. Correlation techniques are widely used in GSM and
30 similar communications systems to perform signal synchronisation, detection and other signal processing tasks.

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Phased array antennae comprise a plurality of antenna elements arranged in an array. Each individual antenna element in the array has an associated feed cable and associated receiver components. By processing and combining the signals received from each of the elements in the array it is possible to control the characteristics of the overall synthetic beam pattern (e.g. beam shape, pointing direction, nulling of interference), for example by applying different amplitude weightings, different phase shifts and time delays to signals received from each of the antenna elements before combining them. Amplitude weightings, phase shifts or time delays may be applied to received signals in the analogue or digital domain, as is well known.

Increasingly, phased array antennae are being employed in cellular telephone networks, for purposes such as maximising traffic capacity using spot beams, interference reduction and the locating mobile handsets. For example, International Patent Application number WO-A-9526116 (Ericsson GE Mobile Inc) describes a phased array cellular base station that makes use of an number of individual phased array antennae, each arranged to transmit a different individual radio channel of a different frequency at any one time. The power radiated by each phased antenna array is selectively controllable to reduce possible interference while maintaining communications with respective mobile units both near and far from the base station.

Another example of a cellular base station that employs a phased array antenna is described in United States Patent US-A-2001027103 (Harris Corporation). In the system of US-A-2001027103, each base station employs a phased array antenna to enable the base station to define its antenna coverage pattern with respect to any mobile transceiver so as to minimise interference from one or more other transceivers, so enabling a reduction in frequency reuse distance.

In practice, there are minor differences in the characteristics of each of the cables, components and individual antennae elements in a phased array antenna so that it is necessary, or at least desirable, to calibrate the phased array antenna and associated receiver system so that optimal performance can be achieved and maintained. It is known to calibrate phased array antennae,

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and associated receivers, by injecting a sinusoidal (sine) wave signal into each of the antenna element feeds and subsequently measuring the phase and amplitude variations through each corresponding receiver channel. It has been found however that such a technique is not optimal when used in certain types of phased array antenna and receiver system and particularly those which operate using digital receiver techniques and which are required to receive wideband signals.

Summary of the Invention

According to a first aspect of the present invention there is provided a method of calibrating an antenna and receiver system having multiple channels, each channel comprising an antenna, feed cable and associated receiver components, the method comprising the steps of:

- (i) applying a wideband calibration signal to each antenna feed, the wideband calibration signal having similar characteristics to an operational signal;
- (ii) measuring a correlation response across a plurality of said channels;
- (iii) deriving an estimate of signal transfer response for each of said plurality of channels based on the correlation response; and
- (iv) applying compensation factors for each of said plurality of channels derived from the estimate of signal transfer response.

In order to optimise performance and increase flexibility, preferred embodiments of the present invention are adapted for use with a phased array antenna system incorporating digital receivers for synthetic beam/null generation and steering. Such arrays comprise a number of antenna elements, with parallel receiver channels comprising cabling, analogue-to digital converters (ADCs) and digital signal processing systems. In normal operation, the outputs of these channels are suitably combined in delay, amplitude and phase to create the desired synthetic antenna beam patterns. This process can

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only be performed successfully if the signal transfer characteristics of each of the channels are known.

In a preferred embodiment of the present invention, said plurality of channels comprise all said multiple channels and, at step (ii), the correlation
5 response is measured with reference to said wideband calibration signal. Alternatively, said plurality of channels comprise all but a selected one of said multiple channels and wherein, at step (ii), the correlation response is measured with reference to said selected one channel.

Preferably, the wideband calibration signal comprises a pseudo-random
10 binary sequence modulated according to a modulation scheme providing similar modulation characteristics to those of the operational signal.

If a phased array antenna and receiver system which is adapted for use with wideband signals is calibrated using a mono-frequency sine wave, as with known calibration arrangements, then the resultant calibration factors which are
15 obtained may only be applicable to a narrow frequency band around the frequency of the sine wave and not to the full bandwidth of the operational signal, as is possible through use of the present invention, because the receiver system may exhibit different characteristics outside this narrow frequency band.

Furthermore with a digital receiver system, differential delays between
20 channels may be introduced due to effects such as ADC clock phasing and skew, latency of data stream processing, storage and buffering activities and interface protocols etc. Preferred embodiments of the present invention are particularly well suited to taking account of such effects when used to calibrate antenna systems employing digital receiver techniques.

In a preferred embodiment of the present invention, either a pseudo-
25 random binary sequence, or a symbol sequence with the characteristics of a typical GSM signal is readily and easily generated by test equipment. Both types of signal possess good auto-correlation properties. GMSK modulation is then preferably applied and the result is up-converted to an operational receiver
30 frequency to provide the calibration signal.

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After processing through the antenna feed and receiver system the calibration signal in each channel is cross-correlated with the original calibration signal, or with the output of one of the receiver channels, to obtain the delay, amplitude and phase characteristics of each receiver channel.

5 Preferred embodiments of the present invention will now be described by way of example only, and with reference to the accompanying drawings, of which:

Figure 1 is a diagram showing a phased antenna array calibration arrangement according to a first embodiment of the present invention; and

10 Figure 2 is a diagram showing a phased antenna array calibration arrangement according to a second embodiment of the present invention.

Detailed description of Preferred Embodiments of the Invention

15 An arrangement for calibrating a phased antenna array and receiver system will now be described with reference to Figure 1, according to a first preferred embodiment of the present invention.

Referring to the Figure 1, a portion of a phased antenna array and receiver system is shown, with four receiver channels illustrated, in which each of the antenna elements in the array of antenna elements 10 are linked by means of switches 12, 13, 14, 15 and respective antenna feeds 17, 18, 19 and 20 to digital receivers 22, 23, 24 and 25 respectively. When the switches 12-15 are set to a first position, signals received at the antenna elements 10 are routed to the digital receivers 22-25 in the normal way. However, when the switches 12-15 are set to a second position – a calibration mode - a calibration signal generated by a signal generator 35 is input to each of the antenna feeds 17-20 and hence to the digital receivers 22-25. An output from each of the digital receivers 22-25 is connected a respective complex (I, Q) correlator 27, 28, 29 and 30. The calibration signal generated by the signal generator 35 is also input directly to each of the complex correlators 27-30 so that they can each perform a complex correlation of the calibration signal received over their

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respective antenna channel with the directly supplied calibration signal. Example outputs of the correlators 27-30 for this first preferred embodiment are shown (32) in Figure 1.

As mentioned above, known calibration methods for use in phased array
5 antennae make use of a sine wave calibration signal or other narrow band signal when attempting to measure a signal transfer response for each of the channels of an antenna array. Conventional methods of calibration thus take little account of the broadband signal reception characteristics of the antenna and receiver components and do not allow delays due to latency or analogue to
10 digital converter clock skew which may be present in digital receiver systems, to be measured.

In this first preferred embodiment, the signal generator 35 is arranged to generate a calibration signal having characteristics of a typical GSM signal. However, the signal generator 35 may be arranged to generate calibration
15 signals typical of the particular mobile communications systems in which the phase array antenna is deployed, if other than a GSM system. In particular, the signal generator 35 operates by applying GMSK modulation to a preselected pseudo-random binary sequence having good auto-correlation properties, and up-converting the modulated signal to the required channel calibration
20 frequency to produce the required calibration signal.

In this first preferred embodiment, each of the complex correlators 27-30 perform a complex correlation of the calibration signals received over the respective receiver channel with the calibration signal supplied directly from the signal generator 35. The outputs from each correlator 27-30 are analysed in a
25 calibration processor (not shown in Figure 1) in order to determine the transfer characteristics of each channel, advantageously based upon bandwidth and modulation characteristics similar to those encountered in normal operation of the antenna and receiver system. In particular, the calibration processor is arranged to search across an appropriate range of signal delays for each
30 receiver channel to find the position of peak response in each correlator output, which identifies the channel delay. As a consequence of the low sidelobes typically associated with the autocorrelation functions of the signal types of

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interest in GSM systems for example, the position of the correlation peak corresponding to the channel delay is easy to identify. The calibration process operates in the complex signal domain and hence "In Phase" (I) and "Quadrature" (Q) output values are produced. For the peak response delay the
5 calibration process may derive the amplitude response for the respective channel using the value of $(I^2 + Q^2)^{1/2}$. Furthermore the channel phase shift ϕ is derived from $\tan^{-1} (-Q/I)$. Therefore only three measurements per channel (delay, amplitude and phase) need to be made by the calibration processor in order to obtain an appropriate set of compensation parameters to enable the
10 antenna feed and receiver system to be calibrated.

The calibration process may be repeated as required so as to compensate for drifts or errors that may be introduced, for example due to changes in ambient conditions or changes in clock signal phasing after each system power up.

15 Thus it can be seen that invention also overcomes problems often associated particularly with digital systems, namely differential delays caused by factors such as analogue to digital conversion clock phasing and skew, data stream processing, buffering and storage.

Referring to Figure 2, in a second preferred embodiment of the present
20 invention, rather than supply the calibration signal directly to the complex correlators 27-30, it may be simpler in practice to use the output of one of the receiver channels as the calibration signal source for cross correlation purposes. This alternative embodiment, which exploits the same principles as the first embodiment, may be adequate for many applications and may be
25 simpler to implement. In this alternative embodiment the calibration processor (not shown in Figure 2) measures the amplitude, phase shift and delay of each antenna receiver channel relative to the channel selected as the calibration signal source.

There are a number of advantages shared by preferred embodiments of
30 the present invention over known antenna and receiver system calibration arrangements.

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Firstly, since the correlation can be performed over a wide symbol span, there is obtained considerable processing gain against noise, thus enhancing the accuracy of the calibration. Secondly the calibration signal has the same or similar spectral and modulation characteristics as a normal GSM signal, so that
5 the effects of filter responses, amplifier group delays etc. will be accurately reproduced in the calibration. Thirdly, the amplitude and phase characteristics of each channel are simply obtained from the real and imaginary results of complex correlations. Fourthly, the position of the easily identified correlation peak permits the delay through each channel to be measured. This may be
10 important when digital receiver techniques are employed, since the latency through digital systems may be significant and may in addition be different at each power up. This can occur, for example, if the DSP or interface clocks are derived from dividing down a high frequency master clock, so that each logic block in the system then has the choice of selecting at random from one of a
15 number of possible clock phases at power up.

It will be appreciated that the invention has been described by way of example only and that variation to the above described embodiments may be made without departing from the scope of the invention.

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CLAIMS

1. A method of calibrating an antenna and receiver system having multiple channels, each channel comprising an antenna, feed cable and associated receiver components, the method comprising the steps of:
- 5 (i) applying a wideband calibration signal to each antenna feed, the wideband calibration signal having similar characteristics to an operational signal;
- (ii) measuring a correlation response across a plurality of said channels;
- 10 (iii) deriving an estimate of signal transfer response for each of said plurality of channels based on the correlation response; and
- (iv) applying compensation factors for each of said plurality of channels derived from the estimate of signal transfer response.
- 15 2. A method according to claim 1, wherein said plurality of channels comprise all said multiple channels and wherein, at step (ii), the correlation response is measured with reference to said wideband calibration signal.
3. A method according to claim 1, wherein said plurality of channels
- 20 comprise all but a selected one of said multiple channels and wherein, at step (ii), the correlation response is measured with reference to said selected one channel.
4. A method according to Claim 1, wherein said wideband calibration signal
- 25 comprises a pseudo-random binary sequence modulated according to a modulation scheme providing similar modulation and bandwidth characteristics to those of the operational signal.

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5. A method according to any one of the preceding claims wherein, at step (iii), deriving said estimate of signal transfer response comprises determining the delay through the respective channel.
- 5 6. A method according to any one of the preceding claims wherein, at step (iii), deriving said estimate of signal transfer response further comprises deriving phase characteristics of the respective channel.
7. A method according to any one of the preceding claims wherein, at step
10 (iii), deriving said estimate of signal transfer response further comprises deriving amplitude characteristics of the respective channel.
8. A method according to any one of the preceding claims, further comprising the step of:
- 15 (v) repeating steps (i) to (iv) to compensate for changes in signal transfer response over one or more of said plurality of channels.

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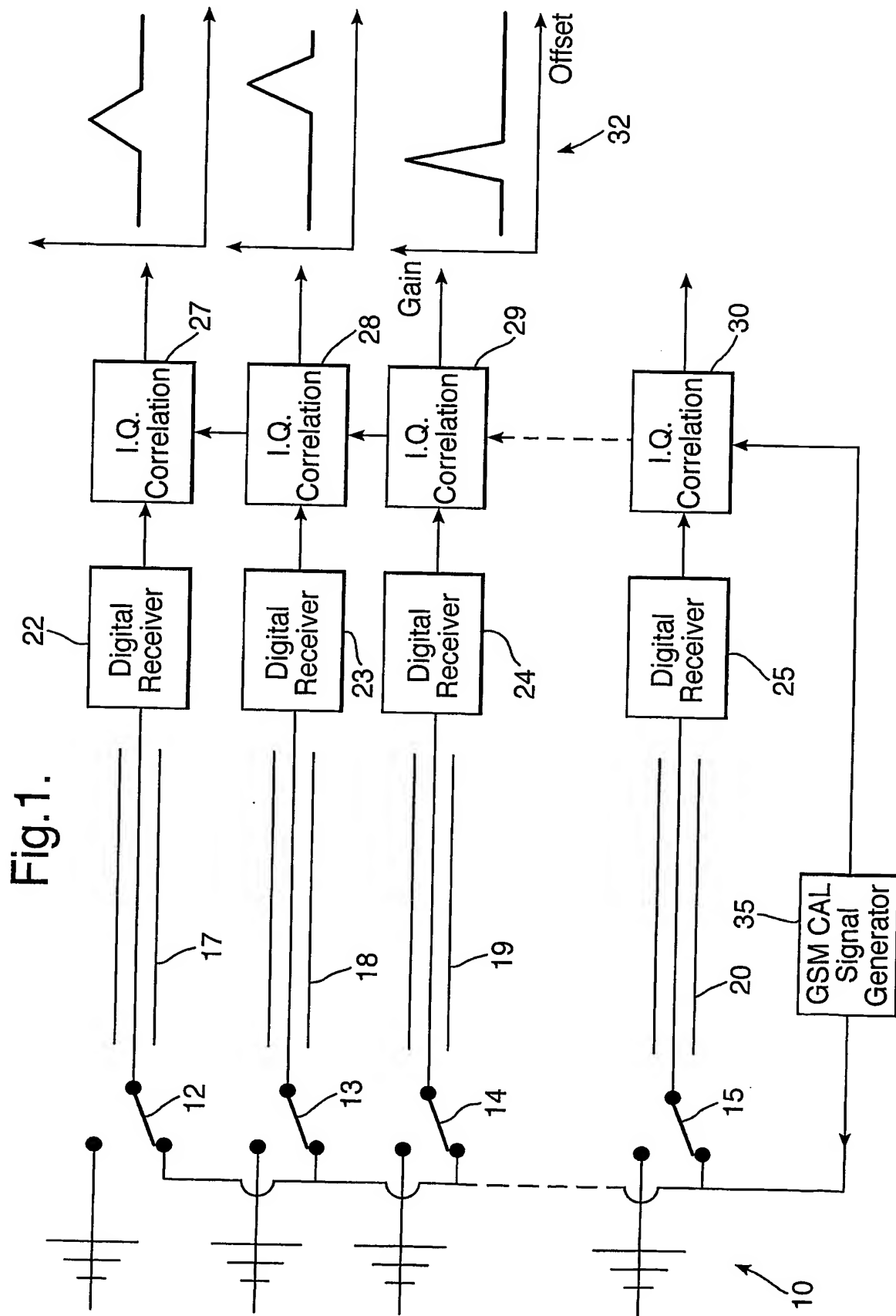
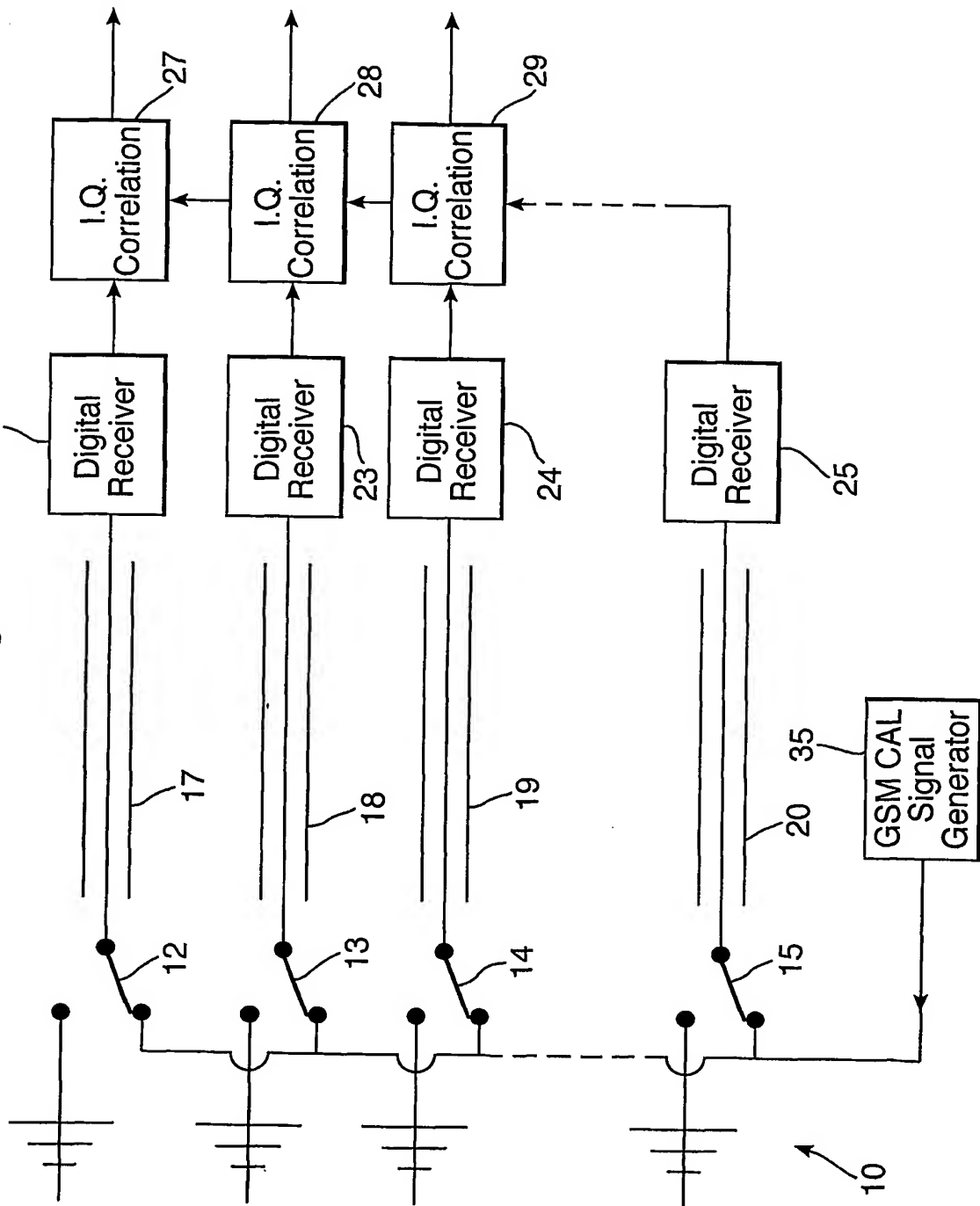


Fig.2.



INTERNATIONAL SEARCH REPORT

International Application No
PC 1 / GB2004/004896

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01Q3/26 H04B17/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01Q H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 938 204 A (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD) 25 August 1999 (1999-08-25) paragraphs '0031!', '0040!' - '0074!'; figures 9-19	1-8
X	US 5 357 257 A (NEVIN ET AL) 18 October 1994 (1994-10-18) column 3, line 46 - column 7, line 39; figure 1	1
X	EP 1 161 001 A (NEC CORPORATION) 5 December 2001 (2001-12-05) paragraphs '0036!' - '0040!'; figure 4	1
	-/-	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

*** Special categories of cited documents:**

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- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
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Date of the actual completion of the international search

15 February 2005

Date of mailing of the international search report

22/02/2005

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INTERNATIONAL SEARCH REPORT

International Application No
PC1/GB2004/004896

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 157 343 A (ANDERSSON ET AL) 5 December 2000 (2000-12-05) column 6, line 13 - column 7, line 39; figure 4	3
A	EP 1 235 361 A (NEC CORPORATION) 28 August 2002 (2002-08-28) figure 3	1
A	WO 97/00543 A (WATKINS-JOHNSON COMPANY; THE BOARD OF TRUSTEES OF THE LELAND STANFORD) 3 January 1997 (1997-01-03) V. Transmit and receive channel calibration	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB2004/004896

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 0938204	A	25-08-1999	AU 6312298 A EP 0938204 A1 CN 1220792 A CN 1108037 C JP 3369466 B2 JP 11046180 A WO 9842093 A1 KR 2000010645 A US 2003186725 A1	12-10-1998 25-08-1999 23-06-1999 07-05-2003 20-01-2003 16-02-1999 24-09-1998 25-02-2000 02-10-2003
US 5357257	A	18-10-1994	NONE	
EP 1161001	A	05-12-2001	JP 3424659 B2 JP 2001345747 A BR 0102966 A CN 1327317 A EP 1161001 A2 US 2001048389 A1	07-07-2003 14-12-2001 13-02-2002 19-12-2001 05-12-2001 06-12-2001
US 6157343	A	05-12-2000	US 6339399 B1	15-01-2002
EP 1235361	A	28-08-2002	JP 3557969 B2 JP 2001156688 A AU 1550601 A BR 0016098 A EP 1235361 A1 CN 1425224 T WO 0139394 A1	25-08-2004 08-06-2001 04-06-2001 29-10-2002 28-08-2002 18-06-2003 31-05-2001
WO 9700543	A	03-01-1997	US 6101399 A AU 6034796 A EP 0832509 A1 WO 9700543 A1 US 6665545 B1 US 2004157646 A1 US 6006110 A	08-08-2000 15-01-1997 01-04-1998 03-01-1997 16-12-2003 12-08-2004 21-12-1999